The Body Has a Mind of Its Own

How Body Maps in Your Brain Help You Do (Almost) Everything Better

Sandra Blakeslee
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Phantoms in the Brain

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Foreword by Oliver Sacks, M.D.

Probing the Mysteries of the Human Mind

“Fascinating.”
—The New York Times Book Review
The body mandala
How does the brain create the mind

• Neuroscientific problem about the brain creating the mind.
• Philosophers – philosophical solutions
• Neuroscientists – materialist assumption
  – The mind is a product of the brain
  – Goal is the try to understand how the brain makes the mind possible.
## Our bodies, Our selves

- What constitutes a person?
- Is a person a body, a mind, a mind *in a body*?
- Does a person have to be human?
- Are all humans persons?
- Could a creature from another planet be a person?
- Can a human lose personhood as a result of brain damage, insanity, or moral transgressions?
peripersonal space—like an aura

Your brain annexes the space around your body
- Your self does not end where your flesh ends

Your body map will blend with the horses body map.

Using tools...
- The bat has been incorporated into your body map.
Does your hand belong to you?

- How do you know it’s your own hand?
- How do you know that you have a body?

- What makes you think you own it?

- How do you know where your body begins and ends?
- How do you keep track of its position in space?
In the 19th century, German physician *Franz Joseph Gall* divided the brain into dozens of personality organs to which the skull was said to conform.
<table>
<thead>
<tr>
<th>Brain is a bordered organ – subdivided into zones and functions.</th>
<th>Lines are blurry</th>
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<tr>
<td>Specialized neurons?</td>
<td>Memories and emotions?</td>
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Dr. Wilder Penfield
electrical stimulation mapping
Out-of-body experiences: from Penfield to present

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Can the brain, when stimulated, yield entirely novel experiences? Blanke et al. (2002) describe a patient who reported spontaneous out-of-body experiences during electrical stimulation of her angular gyrus. These findings, although apparently extraordinary, agree with much earlier reports from a patient tested by Wilder Penfield. Such studies can provide clues about the nature of conscious experience.

Blanke et al. recently described a preoperative epilepsy patient who reported spontaneous out-of-body experiences during electrical stimulation of her right angular gyrus [1]. This study is both interesting and important because it addresses the problem of whether brain activity induced by local stimulation can elicit familiar experiences only, novel combinations of familiar experiences, or experiences that are entirely novel.

The 43-year-old woman in the study suffered complex partial seizures and had temporarily implanted subdural electrodes to identify the epileptic focus. Stimulation at two specific electrode sites over the angular gyrus at the parietal-temporal junction elicited novel vestibular illusions of falling or floating (Fig. 1a). Initial stimulation led to sensations of ‘falling from a height’ or ‘sinking into the bed’. Higher amplitude stimulation led to the report of an apparent out-of-body experience. She reported that ‘I see myself lying in bed, from above, but I only see my legs and lower trunk’. In actuality, the patient was lying in bed with her upper body supported at a 45-degree incline. It is worth noting that despite the patient’s shift in perceived vantage point, her description of the items in view remained veridical – that is, she did not report seeing her entire body and face from above. Subsequent stimulation led to vestibular illusions of lightness and floating above the bed close to the ceiling. Moreover, when the patient was instructed to watch her legs, stimulation of the same site led to the patient to report that her legs had become shorter or that they appeared to be moving towards her face. Similar effects occurred when she attended to her arms.

The findings suggest that distortion of vestibular and somatosensory processing in the angular gyrus can lead to out-of-body experiences. However, given the extraordinary nature of these reported experiences and possible variability in cortical organization among epileptic patients, one might wonder how to consider such a single, albeit remarkable, clinical report.

Pioneering investigations of electrical brain stimulation

Wilder Penfield, a pioneer at investigating the effects of electrical stimulation in conscious humans under local
Stimulation at other sites elicited other behavioral responses: magenta, motor responses; green, somatosensory; blue, auditory. Stars indicate the epileptic focus in the medial temporal lobe.
In 1941 Penfield reported a similar situation. Patient G.A. suffered habitual epileptic attacks that never evoked hallucinations. Yet upon electrical stimulation of her right superior temporal gyrus at point 0 she spontaneously exclaimed: ‘I have a queer sensation as if I am not here... As though I were half here and half not here.’ She reported that she had never felt this way before. Stimulation of point 1 elicited the response that she felt queer again, as if she were floating away. Similar responses occurred for point 3 and for point 5 in the neighboring parietal lobe.
Sensor/visual information disparity?

Difference a matter of quality or degree?

Are experiences dormant?
The senses

- sight
- taste
- hearing
- smell
When you feel the sun beating down on you.

When you swish an ice cube in your mouth.

Skin thermoceptors: warm and cold

Not for body temp regulation
Sense of up vs. down

Inner ear canals

Needed to operate body in the world

Evolved early – half billion years ago

Balance
Nociception

Piercing pain
Heat pain
Chemical pain
Joint pain
Deep tissue pain
Tickle
Itch
Inherent sense of your body’s position and motion in space

Enables one to touch your index fingers with your eyes closed

Two types:

Embedded in cartilage between skeletal joins and keeps track of load and rate of slippage in each joint.

Embedded in muscles and tendons and measures stretch.
Touch receptors send your brain information about pressure.

For example: gentle pressure, deep pressure, sustained pressure, hair follicle bending, and vibration.

In one’s daily life, touch is by far the most prominent of the somatic senses in your conscious mind.
Using active touch of the fingertip, we can distinguish a raised dot .006 mm high and 0.04 mm wide (smaller than Braille) from a smooth surface.

The high degree of spatial resolution is matched by a temporal resolution that enables a Braille reader to process up to 100 characters per minute.

Representation of Braille characters in human nerve fibers.
Experimental Brain Research 81: 589–92
Close association with movement

- proprioception
- touch
- topographic
Classification of afferent fibers by:

- Receptor location: cutaneous vs. deep
- Receptive Field Size: small vs. large
- Adaptation to maintained stimulation: slowly vs. rapidly adapting
Wetness
Hairiness
Fleshiness
Rubberiness

Sensory information
Pain and touch
Complex, composite sensations

Sensory information
Pain and touch
Complex, composite sensations

Wetness
Hairiness
Fleshiness
Rubberiness
Your embodiment is map dependent

- Chart body in space
- Body surface
- Musculature
- Intentions
- Potential for action
- Mirror maps

- Maps are plastic
- Can be reorganized in response to damage, experience, practice
- Formed early in life
- Mature with experience
- Continue to change
- One is unaware of maps

Subjective sense of self
Ability to navigate
MICROSTIMULATION OF SINGLE TACTILE AFFERENTS FROM THE HUMAN HAND

SENSORY ATTRIBUTES RELATED TO UNIT TYPE AND PROPERTIES OF RECEPTIVE FIELDS

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SUMMARY

Tungsten microelectrodes were inserted percutaneously into the median nerve of alert human subjects for recording and stimulation of single nerve fibres. Impulses from mechanoreceptive units in the glabrous skin of the hand were recorded and single afferents were characterized with respect to unit type (FA I, FA II, SA I, and SA II), as well as size and shape of receptive field, and force threshold.

The electrode was then reconnected to an electrical stimulator and short pulse trains (0.25 to 0.5 s, 20 to 100 Hz) were delivered at successively increasing current intensity, while the subject was asked to report any sensation that he noticed in the hand. The first sensation was always that of a localized skin deformation within a small area, typically 2 to 3 mm in diameter, often coinciding with the receptive field of the recorded unit. Spatial matching was also found in many cases for the size, shape and orientation of the perceptive and receptive fields, strongly suggesting that the sensation was accounted for by the recorded unit that had been selectively activated by the current pulses.

There were clear differences between group data associated with the four types of units with regard to the quality of the percepts. Vibratory sensation was reported with all FA II units and was common with FA I units, whereas a sustained indentation was often associated with SA I units. Indirect evidence suggested that activation of SA II units usually did not elicit a sensation. It was confirmed that a single impulse in a single FA I unit may elicit a sensory response in the attending subject, whereas a much larger input was required from SA I units, which are also less sensitive to mechanical stimuli. This was one of several findings supporting the impression that differential receptive properties, even within a group of afferents, were associated with different sensory responses.

It was concluded that a train of impulses in a single tactile unit may produce within the brain of the subject a construct which specifies with great accuracy the skin area of the unit's terminals as well as a tactile subquality which is related to unit properties.
Fig. 5. Spatial properties of receptive fields of (A) an SA I and (B) an FA I unit compared with the spatial properties of percepts elicited by microstimulation through the recording electrode. * Visual matching to circular areas.
Brain maps

Brodmann's areas (3a, 3b, 1, and 2)
Representations of the Body Surface in Postcentral Parietal Cortex of Macaca fascicularis

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The representations are shown on a dorso lateral view of the brain (left) and as they appear “unfolded” from the central sulcus and medial wall of the hemisphere (left).

The heavy lines mark the borders of the two representations. Cortex activated by designated body surfaces are outlined. The representation of individual digits of the hand and foot are outlined and numbered (D, -Ds).

The organization of the representations of the body surface in Areas 3b and 1 of the *cynomolgus macaque*. 
The “unfolding” of the representations of the hindlimb in Areas 3b and 1
“These somatosensory maps are ‘functional’ rather than ‘veridical.’ All parts of the body are not equally represented since representation of a body part reflects its significance for the animal, not the actual space it occupies. The ‘significance’ of a body part is highly correlated with density of its receptor innervation.”

“What is it Like to Be a Bat?” (1974)

“Consciousness has essential to it a subjective character — what it is like aspect...”

Nagel states that "an organism has conscious mental states if and only if there is something that it is to be that organism—something it is like for the organism."
Although the nose is a relatively small portion of the mole’s body, the cortical representation of the nose dominates the somatosensory cortex. The forelimb also occupies a fairly large percentage of cortex, suggesting that it is an important sensory surface as well. Although the moles did not seem to detect prey with their forelimbs, important information about soil density and composition may come from this sensory surface.
Receptive Fields of Barrels in the Somatosensory Neocortex of the Rat

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Topography of Visual and Somatosensory Projections to Mouse Superior Colliculus

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Changes in the Distributed Temporal Response Properties of SI Cortical Neurons Reflect Improvements in Performance on a Temporally Based Tactile Discrimination Task

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human brain holds and continuously updates an internal map of the body

Using tendon vibration distort volunteers’ brains rapidly adjusted the processing of touch information to match information from proprioception – the position to the limbs relative to the body.
Blindfolded subjects held their left index finger with their right arm.

Vibration was applied to the right arm on the biceps tendon.

... a subjective elongation of the left index finger.

The triceps vibration induced a subjective flexion of the right arm and, consequently, a subjective shrinking of the left index.
In an experiment, blindfolded healthy women and patients with anorexia nervosa felt designs in sunken relief (top) and then drew them on paper (tables). The patients had difficulty making accurate drawings, suggesting a deficit in the operation of sense of touch. Brain activity measurements taken while the patients felt the reliefs showed less activity in the right parietal cortex (at right). The author hypothesizes that flaws in tactile capabilities and in the integrative function of the parietal cortex could contribute to faulty body image in anorexics.
Rubber hands 'feel' touch that eyes see

Illusions have historically been of great use to psychology for what they can reveal about perceptual processes. We report here an illusion in which tactile sensations are referred to an alien limb. The effect reveals a three-way interaction between vision, touch and proprioception, and may supply evidence concerning the basis of bodily self-identification.

Each of ten subjects was seated with their left arm resting upon a small table. A standing screen was positioned beside the arm to hide it from the subject’s view and a life-sized rubber model of a left hand and arm was placed on the table directly in front of the subject. The subject sat with eyes fixed on the artificial hand while we used two small paintbrushes to stroke the rubber hand and the subject’s hidden hand, synchronising the timing of the brushing as closely as possible.

It has been proposed that the body is distinguished from other objects as belonging to the self by its participation in specific forms of intermodal perceptual correlation\(^2\). Subjects in our first experiment who referred their tactile sensations to the rubber hand also consistently reported, in both sections of the questionnaire, experiencing the rubber hand as belonging to themselves. Indeed, eight of ten subjects spontaneously employed terms of ownership in their free-report descriptions, for example: “I found myself looking at the dummy hand thinking it was actually my own.”

While the rubber hand illusion does not tell us precisely what ingredient might make only certain forms of intermodal correlation relevant to the self, it does show that intermodal matching can be sufficient for self-attribution.

Matthew Botvinick, Jonathan Cohen
These illusions demonstrate two important principles underlying perception. First, perception is based largely on extracting statistical correlations from sensory inputs. As you feel your unseen hand being tapped and stroked and see the table or dummy hand being touched the same way, your brain in effect asks itself, “What is the likelihood that these two sets of random sequences [on the hidden hand and on the visible table or dummy] could be identical simply by chance? Nil. Therefore, the other person must be touching me.”

Second, the mental mechanisms that extract these correlations are based on automatic processes that are relatively unsusceptible to higher-level intellect. With information gathered by sensory systems, the brain makes its judgments automatically; they do not involve conscious cogitation. Even a lifetime of experience that a table is not part of your body is abandoned in light of the perceptual decision that it is. Your “knowing” that it cannot be so does not negate the illusion. (Just as some people cling to superstitions even while recognizing their absurdity.)

If an assistant taps and strokes your hidden real hand and a visible fake hand in synchrony, the sensations will seem to come from the plastic.
Intact somatosensory system

Original cortical area responding to touches at B

Skin area B Skin area A

Original cortical area responding to touches at A

Two days after damage to nerve B

Area released from inhibition responds to touches at A

Original area responding to touches at A

Six months after damage to nerve B

Area into which sprouting has occurred responds to touches at A

Area released from inhibition responds to touches at A

Original area responding to touches at A
Review

Behavioral and magnetoencephalographic correlates of plasticity in the adult human brain

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ABSTRACT  Recent behavioral and physiological evidence suggests that even brief sensory deprivation can lead to the rapid emergence of new and functionally effective neural connections in the adult human brain.

Until about 10 years ago, it was widely believed by neurologists that no new neural connections can be formed in the adult mammalian brain. It was assumed that, once connections had been laid down in fetal life, or in early infancy, they hardly changed later in life. It is this stability of connections in the adult brain, in fact, that is often used to explain why there is usually very little functional recovery after damage to the nervous system.

Everyone recognizes, of course, that some changes are possible even in the adult brain for otherwise one could not account for phenomena such as memory and learning (1, 2). Yet it is often assumed that, except in invertebrates (1), these phenomena are probably based on rather subtle changes at the synaptic level and do not necessarily involve alterations in the basic circuitry of the brain.

During the last four decades, the use of the microelectrode has completely transformed our understanding of the brain and has resulted in two major new insights: (i) the concept of the “receptive field”—a set of receptors funneling in information from the sensory surface on to single neurons in the brain [e.g., the somatosensory receptive fields studied extensively by Mountcastle (3) and his colleagues in primate S1 and the visual receptive fields described in detail by Hubel and Wiesel (4) in area 17 of the cat and monkey] and (ii) topography—fixed sensory maps (e.g., the somatotopic representation of the body surface in S1 and the retinotopic arrangement of the visual field in area 17).
Plasticity in Adult Somatosensory Pathways

Are there similar effects in other sense modalities such as touch and hearing? It is known that a complete somatotopic map of the entire body surface exists in the somatosensory cortex of primates (26–28). In a series of pioneering experiments, Merzenich et al. (29) amputated the middle finger (see iii below) of adult primates and found that within two months the area in the cortex corresponding to this digit began to respond to touch stimuli delivered to the adjacent digits; i.e., this area is “taken over” by sensory input from adjacent digits.
Merzenich et al. (29) also made three other important observations. (i) If a monkey “used” one finger excessively (e.g., if that finger was placed on a revolving corrugated drum) for an hour and a half each day, then after 3 months the area of cortex corresponding to that finger “expanded” at the expense of adjacent fingers (30). Also, the receptive fields of neurons in this area were found to have shrunk so that they were unusually small. (ii) If a monkey was forced to always use two fingers jointly by suturing two of its fingers together, then after several weeks it was found that single neurons in area 3b had receptive fields that spanned the border separating the two digits (31). In normal animals, receptive fields never cross the borders between digits. (iii) If more than one finger was amputated there was no “take over” beyond about 1 mm of cortex. Merzenich et al. (29) concluded from this that the expansion is probably mediated by arborizations of thalamo-cortical axons that typically do not extend beyond one mm.

This figure—1 mm—has often been cited as the fixed upper limit of reorganization of sensory pathways in adult animals (32). A remarkable experiment performed by Pons et al. (33), however, suggests that this view might be incorrect. They found that after long-term (12 years) deafferentation of one upper limb the cortical area originally corresponding to the hand was taken over by sensory input from the face. The cells in the “hand area” now start responding to stimuli applied to the lower face region! Since this patch of cortex is >1 cm wide, we may conclude that sensory reorganization can occur over at least this distance—an order of magnitude greater than the original 1-mm “limit.”
Fig. 2. Regions on the left side of the face of patient VQ that elicited precisely localized referred sensations in the phantom digits. “Reference fields,” regions that evoke referred sensations, were plotted by brushing a Q-tip repeatedly on the face. The region labeled T always evoked sensation in the phantom thumb; P, from the pinkie; I, from the index finger; and B, from the ball of the thumb. This patient was tested 4 weeks after amputation.

Somatotopic maps of referred sensations in patient FA.
FIG. 4. The Penfield homunculus. Note that the sensory hand area is flanked below by the face and above by the upper arm and shoulder—the two regions where we usually find reference fields in arm amputees.
The case of Tom and Philip...
On April 23, 1903, the radial (ramus superficialis nervi radialis) and both branches of the external cutaneous (N. cutaneus antibrachii lateralis) were divided in the neighbourhood of the elbow. Both nerves were reunited with silk sutures and the wound healed by first intention.

... 

Five hundred and sixty-seven days after the operation (November 12, 1904), the greater part of the affected area on the back of the hand had become sensitive to cutaneous tactile stimuli, and temperatures below 37° C. evoked sensations of warmth.
To show the extent of the loss of sensation produced by the operation.

The anaesthesia to cotton wool and to von Frey’s hairs is bounded by the black line. The analgesia to prick and other cutaneous painful stimuli lay within the red crosses.

The darkness of the affected area is due to its deep red colour compared with the rest of the hand.
Fig. 2.

To show the extent of the loss of sensation twenty-one days after the operation (May 16, 1903). The black line encloses the loss to cutaneous tactile stimuli; the red line encloses the cutaneous analgesia. Wherever these lines are broken the border was an indefinite one.
By July 20 (eighty-six days after the operation), there was no part of the forearm where a prick could not be occasionally appreciated, although in many places this form of sensation was extremely defective. Moreover, considerable changes had occurred in the condition of the hand; the whole of the thumb and the skin over the radial half of the first metacarpal had become sensitive to prick. The analgesic area on the back of the hand was diminishing from its radial aspect.

Fig 10
To show the condition on July 20, 1903 (eighty-six days after the operation). No part of the forearm was entirely insensitive to cutaneous painful stimuli.
Jacques Fabian Gautier d’Agoty, 1746